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Towards the first high-Q treatments for the FCC 800 MHz 5-cell elliptical cavities

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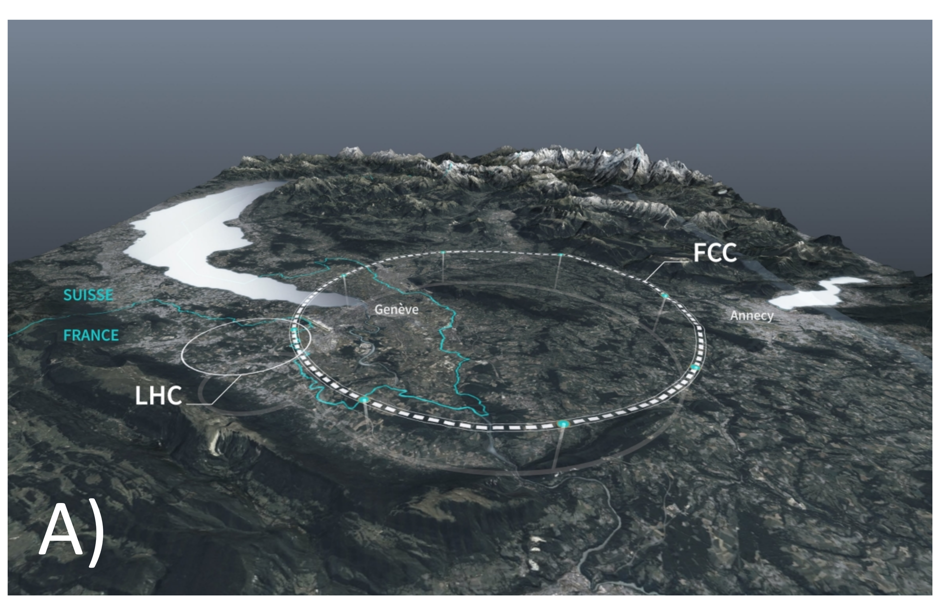
Abstract

Development towards the various realizations of the FCC machine requires optimization of sub-GHz elliptical cavities for high-gradient and high-Q operation, both in pulsed and CW mode, for application in the booster and collider portions. Previous development work validated the proposed 800 MHz 5-cell elliptical RF design, showing reasonable performance after EP treatment. However, the stringent high-Q (3.8e+10) and high-gradient (24 MV/m) goals of the FCC machine cavities will require further development, relying on advanced surface processing techniques developed at 1.3 GHz, such as medium-temperature furnace baking. We describe the development and preparation of 1- and 5- cell 800 MHz cavities for the high-Q program. In parallel, we discuss the design progress and strategies for integrating the 800 MHz cavities into cryomodules to be implemented in both the booster and collider rings.

FCC Introduction



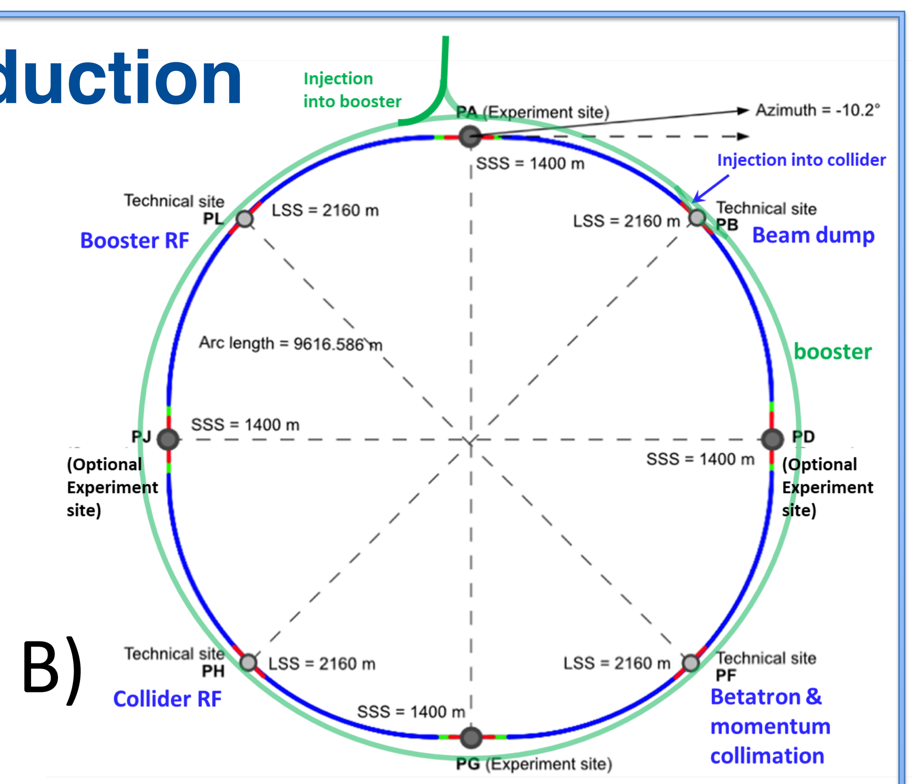


Figure 1: A) Graphical rendering of the proposed FCC footprint, with relation to the LHC, and lac Léman. B) Final 90.7 km layout chosen, showing 4 interaction regions and 8 surface sites configured for FCC-ee [1].

Stage 1 of the FCC is an electron collider (FCC-ee), with phased approaches to Z, W, H, and $t\bar{t}$ physics operation points, to serve first as a Higgs factory, then as an electroweak probe and top factory at the highest planned luminosities.

	Energy (GeV)	Current (mA)	RF voltage (GV)
Z	45.6	1280	0.080
W	80	135	1.05
H	120	26.7	2.1
ttb	182.5	5	11.3

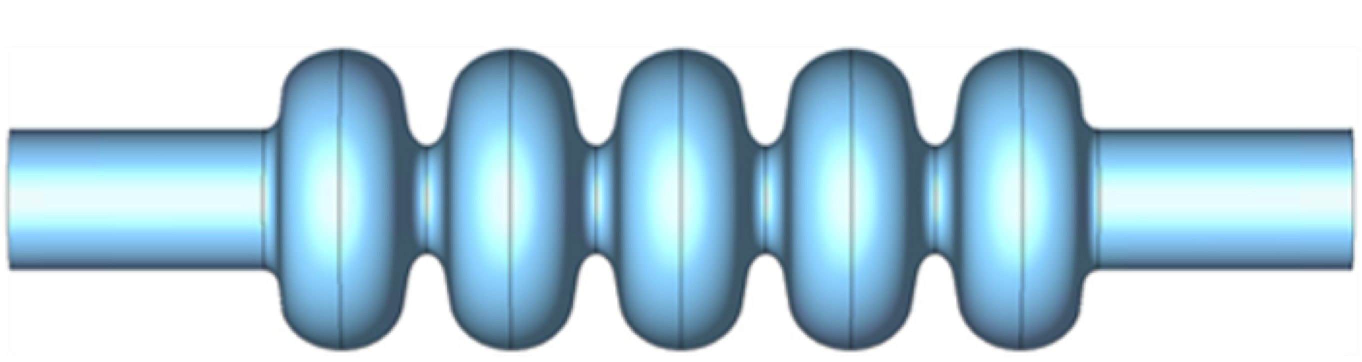
High current machine → High gradient machine

Table 1: High-level RF parameters and physics operating points for FCC-ee. The collider has a budget of 50 MW of CW RF power per ring (100 MW total) to compensate for synchrotron radiation. The booster will accelerate from 20 GeV to the final energies, in pulsed mode, with 10% current and 15% duty cycle.

800 MHz Cavities for Booster and $t\bar{t}$ collider

A combination of 400 and 800 MHz RF cavities will function as the primary accelerating structures. While niobium-on-copper (Nb/Cu) is under development for the 400 MHz resonators, the high quality-factor and gradient needs at 800 MHz require boundary-pushing performance from superconducting bulk niobium.

Figure 2: 5-cell elliptical 800 MHz cavity design for FCC. 24, 56, 112, and 600 cavities are needed for Booster at Z, W, H, and $t\bar{t}$ physics operation points respectively, with an additional 488 for the $t\bar{t}$ collider.



- **Desired performance:**
  - E_{acc} **= 20 MV/m, Q0 = 3.0x10^{10} in operation**
  - E_{acc} **= 24.5 MV/m, Q0 = 3.8x10^{10} in operation**

FCC 800 MHz cavity R&D

A 5-cell prototype fabricated at Jlab has been successfully baseline electropolished [2]. It is currently being prepared for mid-T baking and vertical testing at FNAL [3]. 1-cell cavity drawings have also been produced by FNAL for fabrication at CERN, and will be used to explore and refine mid-T baking, N-doping, and Nb3Sn advanced high-Q RF surface processing recipes.

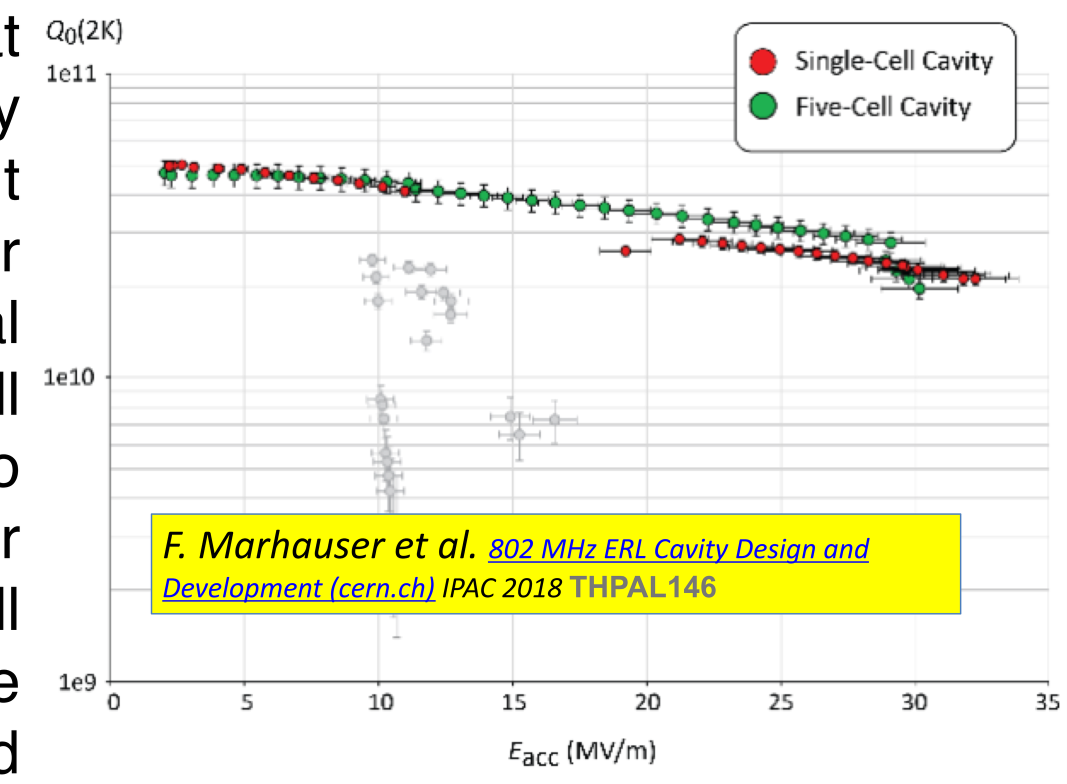


Figure 3: Combined vertical test results for the 5-cell and 1-cell cavities after electropolishing (EP), measured at 2 K.

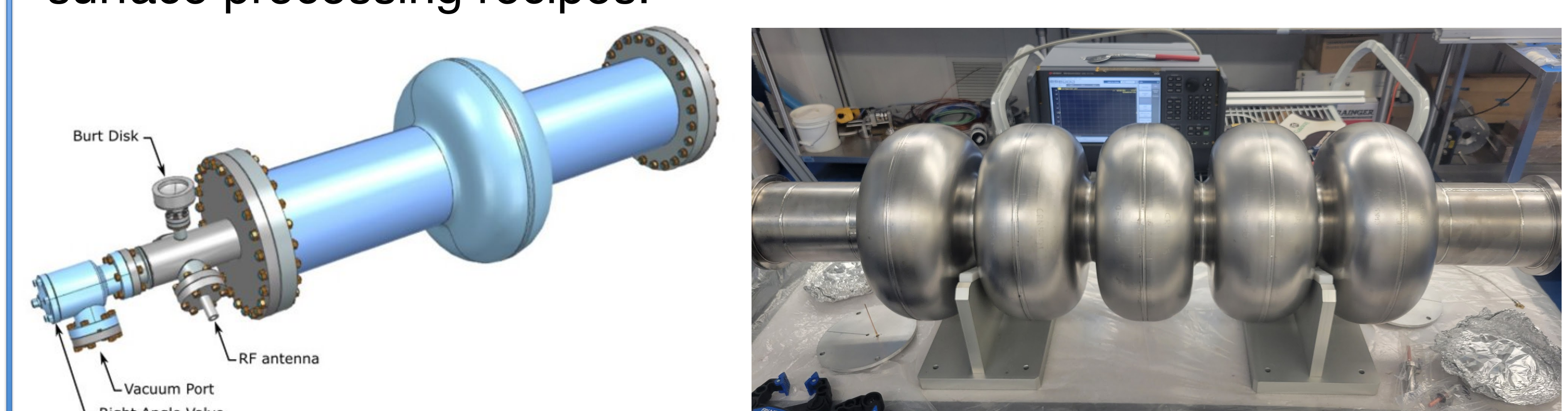


Figure 4: (Left) FNAL1-cell cavity design, prepared for fabrication in-house at CERN. (Right) Jlab fabricated 5-cell 800 MHz prototype cavity, under preparation for mid-T baking and vertical testing at FNAL.

Ongoing 800 MHz systems/cryomodule development

FNAL is undertaking integrated cavity jacket/tuner design for 800 MHz cavities, by adapting the double-lever tuner design used in PIP-II. Additionally, drawing on PIP-II and other large production experience, FNAL is developing both continuous and segmented cryomodule concepts for the FCC 800 MHz cavities.

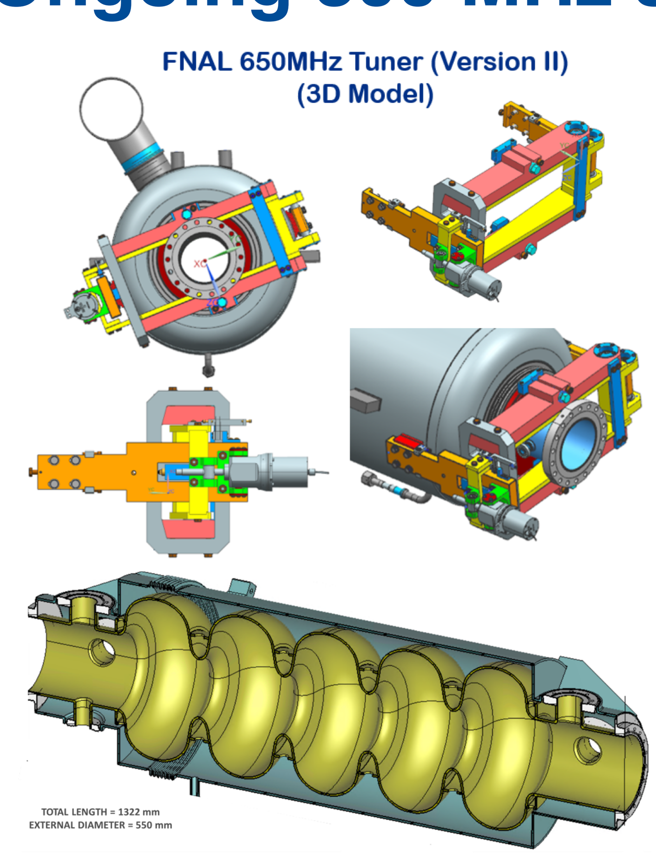


Figure 5: (top) The double-lever tuner design for the PIP-II 650 MHz cavities will form the basis of the FCC 800 MHz tuner design. (bottom) Early proposed helium jacket design for the FCC 800 MHz cavity, under ongoing iterations.

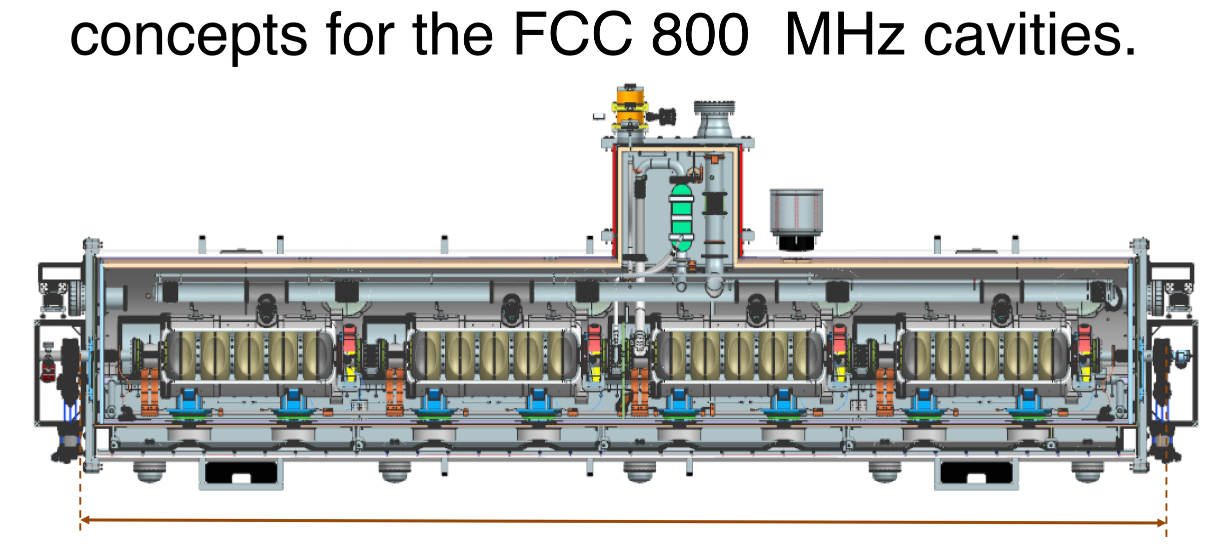


Figure 6: A) FNAL design for the FCC 800 MHz cryomodule, based on the FNAL-designed PIP-II 650 MHz cryomodules.

Conclusions

The FCC is a challenging and ambitious project relying heavily on bulk Nb SRF technology. Current advanced RF surface processing methods are being developed and refined for 800 MHz FCC cavities at FNAL in collaboration with CERN. More consistent, focused support for SRF R&D is absolutely critical to realizing the FCC.

References

[1] M. Benedikt, 2nd annual FCC Workshop, MIT, Boston, 2024. [2] F. Marhauser *et al.*, IPAC28, Vancouver, BC. THPAL14 [3] 6 G. Wu *et al.*, SRF2023 MOPMB030 [4] S. Gorgi-Zadeh. PhD Thesis. 2020.

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